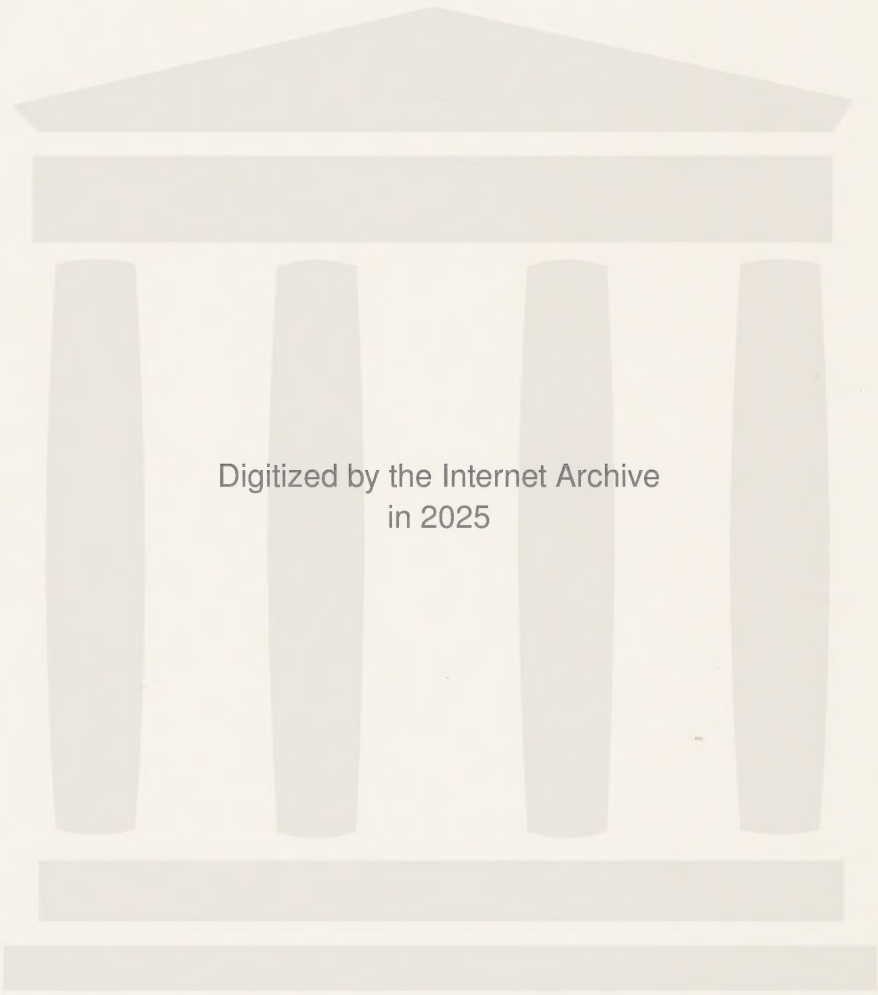
MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

FISHERY INVESTIGATIONS
Series II *Volume* XXI *Number* 3

The Interpretation of Echo Traces

D. H. CUSHING
Fisheries Laboratory, Lowestoft

LONDON: HER MAJESTY'S STATIONERY OFFICE
1957


Digitized by the Internet Archive
in 2025

https://archive.org/details/fishery-investigations-series-ii_1957_21_3

CONTENTS

INTRODUCTION . . . . . *page* 1

I THE SPOT 1

II (a) THE COMET (Sub-types) 2
1. Fingernail trace 5
2. Plate trace 5
3. Sphere trace 6
4. Crescent trace 6

II (b) THE COMET (Interpretation) 6
1. Fingernail trace 6
2. Plate trace 6
3. Sphere trace 6
4. Crescent trace 6

III PLUMES, STEEPLES AND TOWERS . . 8

IV LAYERS 10

V DISCUSSION 15

VI SUMMARY 16

BIBLIOGRAPHY 16

FOREWORD

Hodgson was the first to publish an account of a study of different shaped traces on the paper record of an echo sounder (1950). For one machine working in comparatively shallow water he was able to associate different types of trace with different species of fish. Records from deep water and more extensive regions have shown that the types of echo trace are more closely associated with the sizes of shoals rather than with fish species. In the fairly limited region within which he worked, Hodgson's identifications of species depended on differences in behaviour which were fairly constant; in more extensive environments, however, identification of fish species by behaviour differences might well be expected to break down.

June 1956 D.H.C.

The Interpretation of Echo Traces

INTRODUCTION

FISH traces may be grouped into four types, the 'spot', the 'comet', the 'plume' and the 'layer' (Cushing *et al.* 1952); each type is really an index of how much of the sound beam is interrupted by the fish shoal, irrespective of depth. Thus, a smallish shoal in deep water occupies a small fraction of the sound cone and is recorded on the echo sounder chart as a 'spot' or a 'comet'; in shallow water, the same sized shoal may occupy all or nearly all of the sound cone and be recorded as a 'plume' or a 'layer'. Consequently, in recording fish shoals as four different types of trace, the echo sounder is giving us information about the size of the fish shoal, provided we know the diameter of the sound cone at the apparent depth of the fish trace.

In addition to a very rough estimate of the sizes of fish shoals, the echo sounder can give a fair estimate of the depth of its upper surface; although the record of the depth of the sea bed is a true depth, that from a fish shoal is rarely a true depth, because the fish are often recorded at an angular range, which is somewhat greater than the depth.

In this paper, the four types of trace will be illustrated, and the information that may be gained from particular records will be set down.

I. THE SPOT

Signals from fish are distinguished from noise or interference not by the signal-to-noise ratio but by their consistency for two or more transmissions. So long as the amplification is reduced to keep the paper record fairly clean (i.e., noise is just present), noise signals very rarely appear at the same depth for two or more transmissions. It is quite possible to record a single signal from fish at extreme range, but in itself it cannot be distinguished from noise; hence, it is disregarded.

The minimum signal which can be regarded as from fish is one of one pulse length that occurs twice in succession at nearly the same depth or over-lapping in depth. The pulse length is the time for which the transmitted signal endures and is of the order of one thousandth of a second (one millisecond, or 1 ms.); as the sound travels in sea water at approximately 1500 m/sec., the pulse length in distance is about $1\frac{1}{2}$ m. or $\frac{3}{4}$ fm. A received signal of one pulse length that persists for a number of transmissions at about the same depth can be interpreted as returned from a single fish. The gadoid (or cod-like) spot described by Hodgson (1950) is a trace that consists of a few repeated signals of one or more pulse lengths. As will be seen later, it is really a form of comet, which is only recorded for part of the fish shoal's track across the sound cone. This means that the fish probably live in very small, dispersed shoals in deep water, which is how the cod family often live.

However, the cod family have been recorded in other forms of trace. Fig. 12(e) is a trace of a cod layer in 140 fms. in June from the Barents Sea; I have seen mountainous traces in the Barents Sea, which were identified as cod in June 1952. In July 1955 small comet traces were observed off Spitzbergen and off Bear Island which were identified as cod; again, large comets in 170 fms. off Iceland have been identified as cod (personal communication, Messrs. Kelvin and Hughes Limited). Whiting traces have been recorded as plumes (by me on Cruise V, SIR LANCELOT, 1954), off the Firth of Forth.

Spot traces have been recorded from fish other than the cod family. For example, Fig. 6(a) shows such traces identified as herring off the Dutch coast (the trace was taken by

P. A. de Boer from the Dutch research vessel, ANTONI VAN LEEUWENHOEK) and Fig. 6(c) shows another series identified as herring at Sandettié. Both traces were compressed comets. This is an effect of slow paper speed; the traces become compressed laterally because each mark overlaps its predecessor to a considerable extent. This does not matter in large traces, but in the case of small traces the shape recorded on the paper can become compressed.

II (a) THE COMET (Sub-types)

The simplest comet trace is that from a single fish swimming at one depth across the sound cone when the ship is laid. At the edge of the sound cone the fish is recorded at a range greater than the true depth; thus, as the fish approaches the centre of the sound cone its range shortens until it reaches the centre, when its true depth is recorded. As an echo sounder which uses a paper record transmits at a constant repetition frequency, the horizontal length of the trace on the paper is a function of the depth and the speed of the fish. When the ship is steaming, however, the trace is considerably shorter, at extreme speeds becoming compressed into a spot.

In the following analysis of the nature of the comet trace, three assumptions will be made:

I. Fish and fish shoals move in one direction at the same depth, so they are confined to a conic section of the sound cone in the plane normal to the axis of transmission. For simplicity it is assumed that this conic section is circular.

II. The relative speed of the ship with respect to the fish is constant during the recording of any one trace.

III. The fish shoals retain their shape, size and packing arrangement during the recording of any one trace.

Fig. 1(a) shows the tracks of two hypothetical single fish across the sound cone as seen from the echo sounder; the ship is laid.

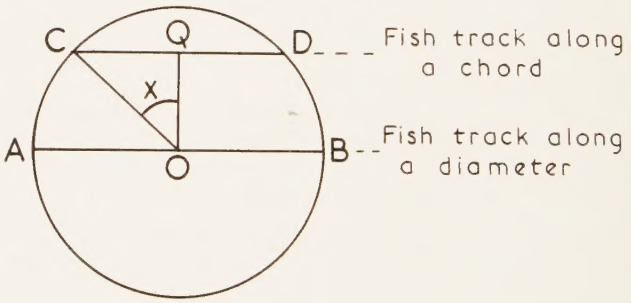


Fig. 1(a). *A conic section of the sound cone normal to the axis of transmission at depth Za. The circumference of the circle is at range Ze defined by the directional character of the transducer and by the signal amplitude returned from fish.*

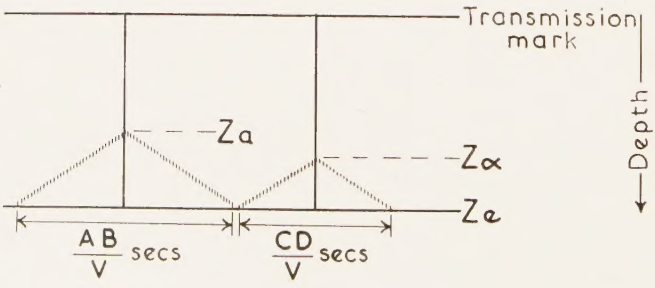


Fig. 1(b). *Paper records on the echo sounder of the fish tracks shown in Fig. 1(a). Za is the range at Q on Fig. 1(a). Each signal extends in range for one pulse length.*

Fig. 1. *Two 'comet' traces from single fish at the same depth.*

If the fish swim at V m/sec., they take AB/V or CD/V secs. to cross the sound cone. The ratio of the times (or horizontal extents of the traces on the paper record) is proportional to sec x ($AB/CD = AO/CQ = CO/CQ = \sec x$) i.e. inversely as the departure of the fish track from a diameter.

Fig. 1(b) shows how the echo sounder records these relations. The range to O is Za, the true depth; the range to Q, $Z\alpha$, is the minimum range of the fish travelling along CD. Ze is the extreme range at which signals from fish are received.

Thus, differences in range of echo traces from fish at the same depth are functions of the departure of the fish track from the diameter of the conic section normal to the axis of transmission.

The horizontal dimension of the paper record measures time, t. Comparing different depths, t becomes increased as in Fig. 2 and so the horizontal extents of the traces increase proportionally to depth; signals are received from a single fish as far as $2Ze$.

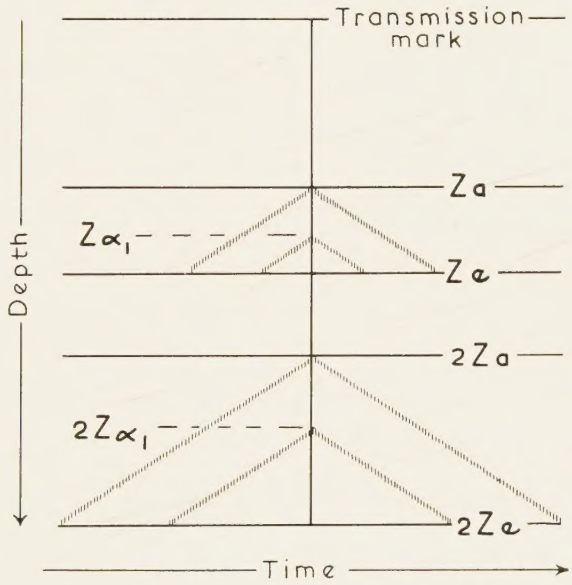


Fig. 2. *The relation between 'comet' traces at different depths.*

The slopes of the traces at different depths in Fig. 2 are virtually the same (if the sound cone is a symmetrical one); slight differences in slope occur due to differences in sec x, but these may be neglected. Differences in the curved head of the comet trace occur and these are functions of range, i.e. at greater depths the angles subtended by fish tracks are greater and so the curve, expressed on the paper record as per unit time, becomes exaggerated. Differences in shape are in the main due to differences in velocity, either between fish at the same time or between ship and fish at different times. When the ship is steaming they are usually due to variations in the ship's speed, but when the ship is laid, they are due to differences in the angular speed of the fish.

From the traces shown diagrammatically in Figs. 1(b) and 2, the tracks of the fish and their true depths could be specified, because Ze is known. In practice the departure of the fish track from the diameter is unknown and therefore it is possible in some small degree to confuse the true depths of two fish shoals, one of which comprises few fish and the other of which comprises many fish; the latter will have a greater horizontal extent than the former, being recorded at a greater angle from the vertical. If the two shoals were at the same true depth, recorded at the same range on the paper record, one would then think that the trace of greater horizontal extent came from fish that were slightly deeper.

Because Ze is unknown, it is impossible to measure the true depth of a fish shoal off the axis of transmission. However, a rough attempt at it may be made by expressing the ratio of maximum to minimum range ($Ze/Z\alpha$) as per unit time. The diameter tracks con-

tinue for a longer time on the echo paper and those traces with the sharpest change per unit time will be the nearest approaches to the diameter tracks.

Fig. 3 shows traces from the drifter OCEAN BREEZE lying off Wexford in January 1953. There is a diffuse trace in midwater, but the records are remarkable for the most extraordinary comet traces. $Ze/Z\alpha$ is tabulated as follows:

Serial number	$Z\alpha$ (*fm.*)	Ze (*fm.*)	$\frac{Ze}{Z\alpha}$	t (*min.*)	$\frac{Ze}{Z\alpha} \cdot \frac{1}{t}$
1	4·0	16·0	4·00	3·2	1·25
2	3·5	15·0	4·29	2·5	1·72
3	1·0	10·5	10·50	2·75	3·82
4	2·0	9·5	4·75	2·2	2·16
5	8·0	12·0	1·50	2·0	0·75
6	7·0	18·0	2·57	3·0	0·86
7	2·0	4·0	2·00	1·0	2·00
8	7·0	18·0	2·57	6·0	0·43
10	0·5	11·0	22·00	3·2	6·87
11	1·0	9·0	9·00	2·5	3·60
12	1·0	11·0	11·00	2·0	5·50
13	10·5	16·0	1·52	4·5	0·34
14	12·5	13·0	1·04	1·0	1·04
15	3·0	12·0	4·00	3·0	1·33
16	15·0	17·0	1·13	1·5	0·75
17	2·5	10·0	4·00	5·0	0·80
18	9·5	11·0	1·16	1·75	0·66
19	15·0	16·0	1·07	1·0	1·07
20	15·0	16·0	1·07	1·0	1·07

From this table, the traces may be grouped as follows:

	Serial numbers	$Ze/Z\alpha$
A	14, 19, 20, 16, 18	Below 1·5
B	13, 7, 6, 8	1·5 to 3·9
C	17, 15, 1, 2, 4	4·0 to 8·9
D	11, 12, 3, 10	9·0 +

Group D includes the traces in which the change of range/unit time ($Ze/Z\alpha \cdot 1/t$) was the most and Group A includes those in which it was the least. Therefore the traces in Group D are the best estimates of tracks on the diameter of the conic section, so $Z\alpha = Za$, the true depth. It will be noticed that the traces in Group D are shallow ones, whereas those in Group A are deep ones, i.e. a diameter trace is less likely in deep water than in shallow water, so the uncertainty of estimating the depth of a comet trace increases with depth, up to a middle depth, before the sound cone becomes attenuated to a pear-shaped sound envelope.

The comet traces shown in Fig. 3 are each produced by a number of objects because at minimum range ($Z\alpha$) the trace is longer than one pulse length. The number of pulse lengths recorded at minimum range is the most reliable index of the size of the shoal. It cannot

Fig. 3. *'Comet' traces observed by the drifter* Ocean Breeze *off Wexford in January*, 1953. *The diffuse trace in the background is probably due to herring.*
(Marconi Seagraph)

yet be more than an index because we do not know to what extent sound energy is scattered or absorbed by a fish shoal. However, the following types of comet trace may be distinguished:

1. *Fingernail trace.* This is a comet trace of one pulse length at all ranges, which is a series of successive signals from a single fish; if there were two fish swimming together, the slight difference in ranges would produce a signal longer than one pulse length. It is theoretically possible for signals from two fish widely separated to arrive at precisely the same time, but it is very unlikely that the fish would both remain at the same range

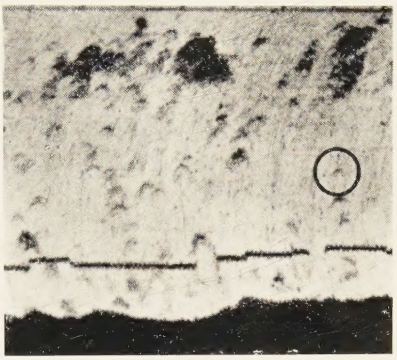


Fig. 4. *A 'fingernail' trace*
(reproduced by permission of Messrs. Kelvin & Hughes; MS 24). Fig. 13. Echo Fishing.

relative to each other. Hence when this trace is observed, we can be sure that the signal is being scattered back from a single fish. Such a trace is illustrated in Fig. 4.

2. *Plate trace.* A horizontal layer of fish or 'plate', would show minimal vertical extent at minimum range because the difference between the maximum and minimum ranges is reduced by half when the shoal is equally spread on either side of the axis of transmission. Such a trace is shown in Fig. (5b), which was generally identified as mackerel.

Fig. 5(a). *A 'sphere' trace, probably due to cod, in the Barents sea.*
(KH MS 21b)

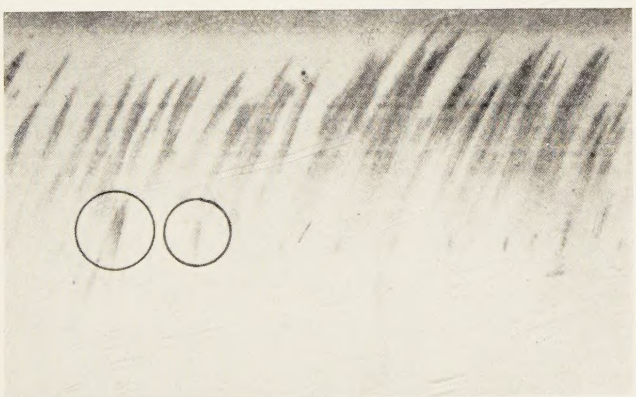


Fig. 5(b). *A 'plate' trace due to mackerel.*
(KH MS 24)

3. *Sphere trace.* This is a comet trace, the vertical extent of which is constant at medium ranges. This means that the difference between maximum and minimum ranges is constant; this would occur only if the fish shoal was in the shape of a sphere. Such reasoning only applies to a medium angular range, because at extreme angular range, only part of the shoal is recorded, because there the sensitivity of the receiver is considerably reduced. Fig. 5(a) shows a record of small shoals of large fish from the Hope Island Deep Water.

4. *Crescent trace.* Most comet traces are of this form, where the greatest vertical thickness occurs at minimum range; this thickness is the best estimate of the size of the shoal in pulse lengths, i.e. in units of $\frac{3}{4}$ fm. It will be subject to an angular error to the degree of departure of the minimal range from the true depth.

II (b) THE COMET (Interpretation)

From comet traces information can be gained on:

(*a*) horizontal extent of the fish shoal. Fish shoals are 'illuminated' by the echo sounder for longer on tracks that cross the axis than on tracks that do not. Similarly, up to a medium depth they are 'illuminated' for longer at greater depths;

(*b*) relative speeds of different fish shoals, e.g. when the ship is laid, an idly swimming shoal will give a long extended record on the paper, whereas at the same depth a very rapid shoal might produce a fairly sharp comet;

(*c*) sizes of fish shoals. Because the extreme angular range of any given number of fish at one depth is unknown, it is impossible to specify exactly the depth of any comet trace. The error is probably never greater than an over-estimate of 10%, but this may on occasion be important.

The sub-types of comet trace give certain information, as follows:

1. *Fingernail trace*, consistently of one pulse length, echoes from a single fish.

2. *Plate trace*, with the shortest vertical extent at minimum range, echoes from a horizontal layer of fish.

3. *Sphere trace*, consistently of the same number of pulse lengths, echoes from a sphere of fish.

4. *Crescent trace*, of many pulse lengths at minimum range, a shoal of greater vertical extent than horizontal.

'Comet' traces have been identified as sprats (Hodgson, 1950), capelin (Cushing *et al.*, 1952), cod (Cushing*), herring (Cushing*), pilchards (Cushing*), mackerel (Richardson*), carp, roach, perch, *Coregonus wartmanni*, *Amiurus* (Schärfe, 1952) and anchovies (Furnestin, 1953). Sprats, capelin, cod, herring, mackerel, pilchards and anchovies have also been identified in traces of other types. Nearly all these 'comets' are crescents, the spheres and plates being curiosities. The thickness of the 'comet' could well be used as an index of shoal size, which might well be different in different species; with present methods, however, an individual 'comet' trace can very rarely be identified.

There is, however, a further possibility: considering traces as combinations of 'comet' character, as shown in Fig. 6. Fig. 6(a) shows a spotty trace of herring off the Dutch coast in October; the ship is steaming and each spot is probably a compressed 'comet'. Fig. 6(c) shows a dense trace of herring in December at Sandettié, with the ship lying. The shallow parts of the trace are composed of small comets, each of which has a short vertical extent; the fact that a similar structure is not shown in the deeper parts of the trace is attributed

*Unpublished.

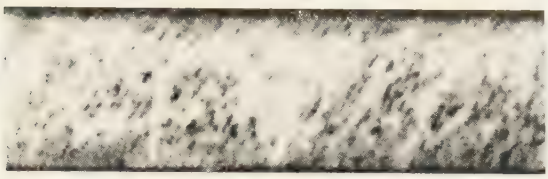


Fig.6(a). *A spotty trace of herring taken off the Dutch coast in October by the* Antoni van Leeuwenhoek. (KH MS 21)

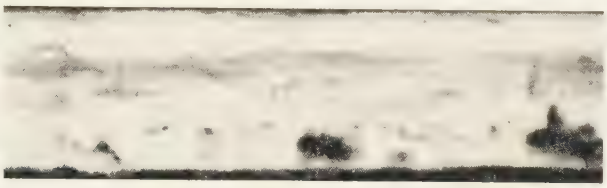


Fig.6(b). *Three varieties of 'comet' trace taken off the Scottish north-east coast in October.* (Marconi Seagraph)

Fig.6(c). *A complete trace of herring from Sandettié; the small 'comets' at the surface merge into a continuous trace in deeper water.* (KH MS 26b)

to the increase in the number of fish shoals illuminated by the sound beam at the greater depth and consequently the signals add up, giving a diffuse record. The difference between Fig. 6(a) and Fig. 6(c) is probably due to the degree of packing of the shoals, those at Sandettié being close together and those off the Dutch coast being far apart.

Fig. 6(b) shows three varieties of 'comet'. The first are small, stubby 'comets' from smallish shoals; the second are large, intense 'comets', extending vertically for a considerable extent; lastly, there are long, low 'comets', that are almost layer-like. The first are small and rapid shoals, the second are slowish, large and thick shoals and the last are small shoals which are moving very slowly indeed. The differences between the three traces are really differences in the ship/fish relative speeds; as the ship was lying, these differences are differences in the angular speeds of fish shoals.

It is concluded that there are three ways in which the 'comet' trace can be made to yield biological information:

(*a*) By giving a rough index of shoal size.

(*b*) By giving a rough index of the packing of small shoals in a large shoal.

(*c*) By giving a relative index of the speeds of different shoals.

III. PLUMES, STEEPLES AND TOWERS

Traces in this group are all of considerable vertical extent; in fact, the first signals received from the edge of the sound envelope are always extensive and often intense. (See for example, Fig. 10). This may only be interpreted as a recording of depth to the shoal. Such traces are, however, more extensive horizontally than they are vertically; an exception is shown by Furnestin (échogramme 24, 1953) each trace of which consists of a few signals, although each extends in depth for 20 m. or more. (Fig. 7)

The 'plume' trace proper and the 'tower' trace are shown in Fig. 8 (from Hodgson 1950, Fig. 6) both of which are traces of pilchards. There are two differences in shoal character between them, firstly, that the 'towers' nearly touch the bottom, whereas the

Fig. 7. *Deep narrow traces of sardines (from Furnestin*, 1954).
(Echogramme 24)

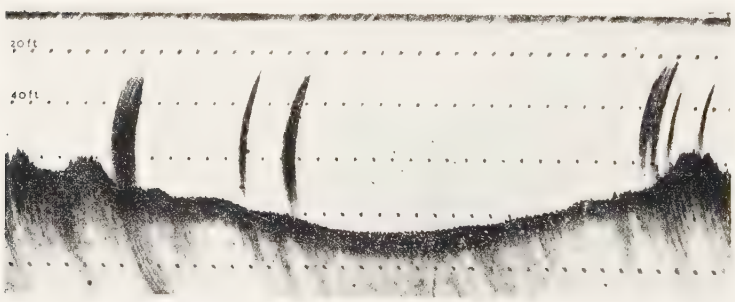


Fig. 8. *'Plume' and 'tower' traces of pilchards (from Hodgson*, 1950).
(KH MS 12)

'plumes' lie clearly in the midwater, and secondly that the 'towers' are much more extensive horizontally than the 'plumes'. It will be noticed that the initial signals are of strong intensity all the way down, which means that the shoal is roughly of that depth, the angular divergence from the axis presumably decreasing with depth. A further point is that the smaller 'plume' has the comet character at the top and that the 'tower' traces tend to be composed of a number of 'comets'.

A 'plume' trace that appears to stand on the bottom of the sea is sometimes called a 'steeple' by fishermen. Fig. 9 (from Cushing *et al.* 1952) shows five 'steeple' traces taken off

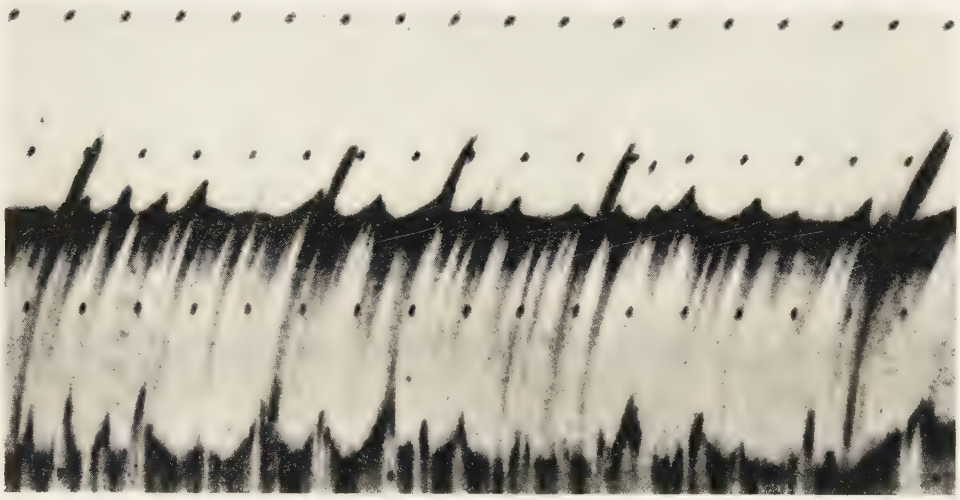


Fig.9. '*Steeple*' *traces taken off Flamborough Head* (*from Cushing* et. al., 1952).
(KH MS 12)

Flamborough Head. Signals of strong intensity extend right to the bottom, so that fish trace and sea bed are indistinguishable, hence the shoal itself must extend quite close to the bottom. The only way of distinguishing the 'steeple' traces from wrecks or pinnacles is that the fish traces do not usually appear on the second echo, or if they do, as in Fig. 9, the intensity of the signal is much reduced, the second appearing as only a very thin shadow of the first. The reason for this effect is that signals from the bottom are perhaps ten times or one hundred times as strong as signals from an ordinary fish shoal.

Large traces near the bottom sometimes show an effect which appears to extend through the bottom: the signals from the bottom beneath the fish shoal are sometimes more extensive than the usual signal from the bottom. The effect can be seen in Figs. 8 and 14; a strange point is that it sometimes occurs when there is a clear gap between the fish trace and the sea floor, so it cannot be always composed of signals from the fish shoal from extreme range, a range greater than the true depth of the sea. A possible explanation is that there is some sort of multiple reverberation between fish in a fish shoal. Many 'plume' traces show a decrease in signal intensity with increasing depth; perhaps this expresses an exponential decay of multiple reverberation. The fact that the effect appears amongst bottom signals when a large fish trace is near the bottom, yet clear of it, suggests that there is a reverberation between the fish and the sea bed as well. The suggestion of multiple reverberation may not be very far fetched, as some experimental results obtained by Cushing and Richardson (1955) could well be explained if multiple reverberation did take place.

The relation between fish signals and bottom signals is illustrated in another way in Fig. 10; here a 'plume' trace is shown casting a shadow on the bottom—where no bottom signal is received. Records of this type are rare and it means that the fish completely occluded the sound beam.

'Plume' traces have been identified as pilchards (Hodgson, 1950, Cushing*), anchovies

*Unpublished.

Fig. 10. *A fish trace that casts a shadow on the bottom.*
(Bendix)

(Furnestin 1953), herring (Cushing*), and whiting (Cushing*). 'Steeples' and 'towers' have been attributed to whiting, herring and pilchards. The fish species recorded have in common the character of living at some periods in deep and extensive shoals; it is possible to make rough estimates of the sizes of the shoals, horizontally and vertically. For example 'plume' traces of herring and pilchards are both found during their feeding seasons, the shoals being 10-30 fms. deep and 50-250 yds. across.

IV. LAYERS

Echo sounders have recorded a number of layers in the sea, not all of which have been attributed to fish. Complex layers may be distinguished from uniform layers: the first are aggregations of trace types already described, 'comets', 'plumes', 'steeples', etc., whereas the second are diffuse, continuous and with no apparent internal structure. In general, the complex layers are layers of fish shoals, whereas the uniform layers are sometimes not composed of fish, but of plankton; there are, however, many uniform layers that are certainly composed of fish, especially in deep water, where patchiness may be masked by the integration of signals from the same range at many angles. The point was noticeable in the report identifying a shallow scattering layer as being due to larval pilchards (Burd and Lee, 1951). When the layer was first observed in May 1950, the larvae were very small (c. 12 mm. in length); in August 1950 the trace of the echo layer had become patchy and the pilchards had grown to become little fish (c. 50 mm. in length). Plankton has been recorded in Windermere as a thin diffuse layer, which was composed of copepods and cladocerans at a density of 28 animals litre (Cushing, Lee and Richardson; in press); a patchy trace of plankton has been recorded from the North Sea, caused by euphausiids swarming at the surface under a full moon (Cushing and Richardson, 1956). The generalization, however, remains that fish often produce patchy traces, but fish larvae in their early stages only produce diffuse and continuous layers.

A series of complex larger traces is shown in Fig. 11. The first (11b) is a layer of 'comets', in which the 'comets' are visible down to the bottom of the trace; the fish producing this trace are probably herring, as are those in Fig. 6(b), in which 'comet' traces disappear in the deeper parts of the trace. The difference between the two types of complex trace is probably one of the density of packing of the small shoals within the large shoal, i.e. Fig. 11(b) shows small shoals loosely packed and Fig. 6(b) shows small shoals tightly packed.

Fig. 11(a) shows a layer of quite different character. The midwater layer is composed of 'comet' traces of different sizes, the larger ones at the top and the smaller ones at the

* Unpublished.

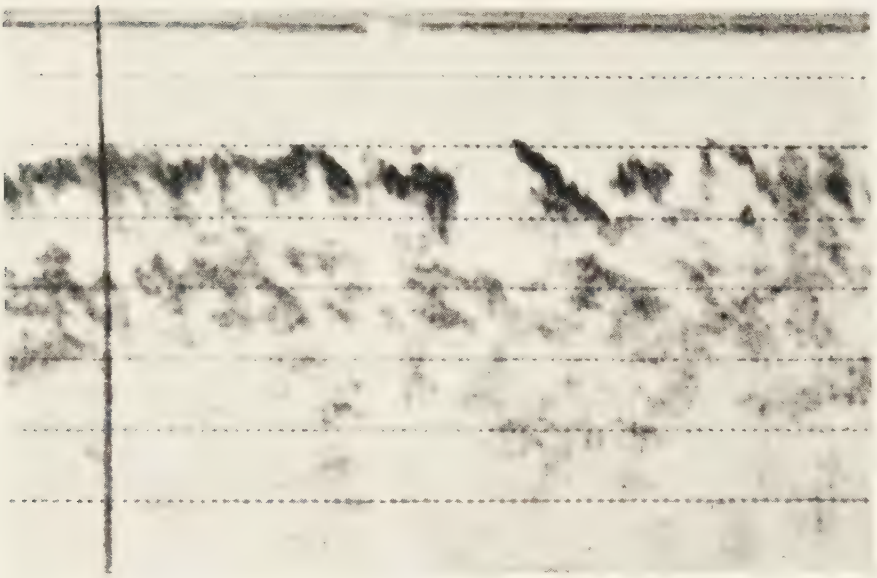


Fig. 11(a). *A layer of 'comets' due to pilchards off Start Point; the traces are of very different sizes.*
(Marconi Seagraph)

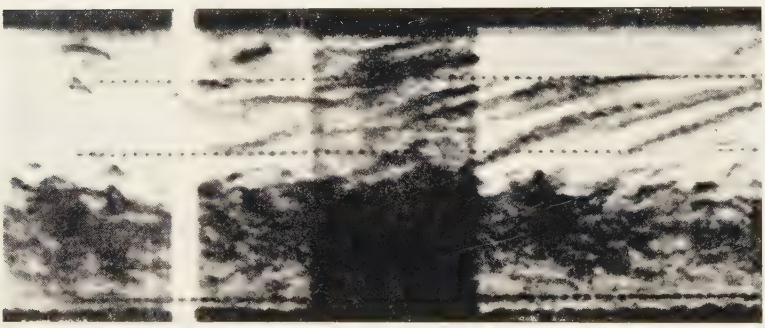


Fig. 11(b). *A layer of 'comets', possibly due to herring; these traces are all of the same size.*
(Marconi Seagraph)

Fig. 11(c). *A layer of short 'plumes', due to herring over the Norfolk Banks.*
(KH MS 24)

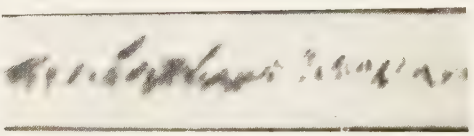


Fig. 11(d). *A layer of complex traces, due to sprats in the Barrow Deep.*
(reproduced by permission of Messrs. Kelvin & Hughes). Fig. 18. Echo fishing.
(KH MS 22)

Fig. 12. *A series of layers.*

Fig. 12(a). *The echo layer at the thermocline at* 15 *fms. Off Whitby in September.*
(Marconi Graphette)

Fig. 12(b). *The 'veil' trace of herring in the Norwegian sea at about* 140 *fms.*
(from Devold, 1953)
(Elac Echograph)

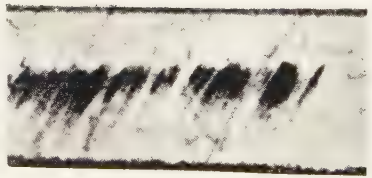


Fig. 12(c). *A winter layer due to herring at* 8 *fms. at Sandettié.*
(from Skipper George Leslie).
(KH MS 20)

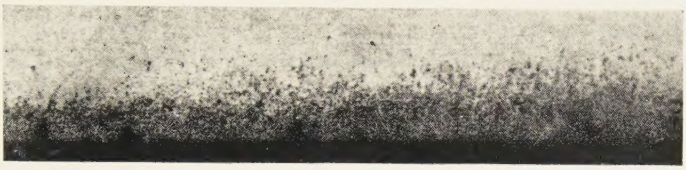


Fig. 12(d). *A 'bottom scattering layer' at 30 fms. that extended from Start Point to St. Catherine's Head in April*, 1952.
(KH MS 26b)

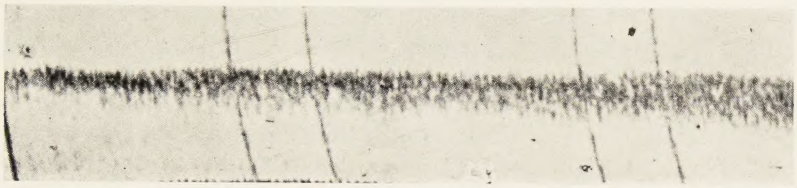


Fig. 12(e). *A layer due to cod at* 140 *fms. in the Barents Sea.*
(KH MS 21)

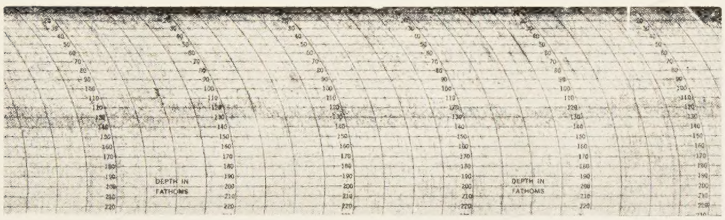


Fig. 12(f). *A trace of the deep scattering layer* (from Boden, 1950) *at* 130-140 *fms.*

bottom of the layer. The layer was identified as being composed of pilchards off Start Point n May 1952. A third layer is that shown in Fig. 11(c), a layer of 'plumes' over the Norfolk Banks in October, probably due to herring. Fig. 11(d) shows a layer of sprat traces recorded n the Barrow Deep in November; it is composed of large 'comets', 'plumes' and 'chunks'. Such layers are usually attributable to fish shoals in fairly shallow water and the same rough estimates of individual shoal size indicated above may be used. In deeper water, a diffuse race is more probable because a given signal is likely to be made up of components from a arger number of ranges.

The simplest case of a uniform layer is that associated with the thermocline (Fig. 12(a)). The layer lies consistently at one depth and is no thicker than one pulse length. This in tself makes it highly improbable that signals could be returned from any point but that on he axis of transmission. Consequently the trace is one of the few the depth of which is accurately recorded. The fact that in fairly shallow water, the signals are returned from the axis only suggests that the objects producing the trace are smaller than fish, for otherwise we would expect signals from the edge of the sound envelope, producing thicker traces. When such traces have been investigated, an association with the presence of plankton organisms has been established (Cushing, Lee and Richardson; in press).

Uniform layers of fish traces are shown in Figs. 12(b) and (c). Fig. 12(c) is a large trace rom winter herring at Sandettié (from Skipper George Leslie). Although this trace might vell be described as an agglomeration of 'plumes', the diffuse upper edge (first noticed by Hodgson, 1950) can only be attributed to weak signals at short range. This probably means hat above the main body of the shoal very small shoals are swimming in dispersed formation; at a shallower depth, or with the ship lying, such a trace could appear like that shown in Fig. 6(b), a thick trace with 'comets' dispersed amongst its upper surface. The

autumn pilchard shoals with their very hard black edge, noted by Hodgson, presumably have no shallow outriding shoals.

In very deep water, the uniform trace may be caused by sums of individual signals, each of which is received from single fish or very small shoals. Fig. 12(e) illustrates a layer due to cod in 140 fms. off Bear Island. At such a depth, the conic section in the plane of the sound envelope normal to the axis of transmission is quite wide; each signal will consist of a sum of successively greater ranges contributed from fish lying on concentric circles of successively greater radii. However fish are distributed, the greater the diameter of the circle, the greater the number of fish on its circumference—so the greater the range, the greater the number of fish contributing to the signal. Now, as the range diverges from the axis of transmission, so the transmitted signal becomes weaker, consequently the signal returned per unit number of fish along a radius of the conic section of the plane of the sound envelope normal to the axis of transmission will be distributed as in Fig. 13. Fig. 12(e) illustrates the point that the greatest intensity of received signal is observed in about the middle of the layer; the same effect has been observed in hake 'layers' and in cod 'layers'. The effect is likely to be observed so long as the layer of fish itself is not very thick.

The case is really the same as that illustrated in Fig. 5, for the axis of transmission is a relatively uncommon position for a number of fish and this becomes more so in deep water. A consequence of this treatment is that in deep water, when signals from single fish are

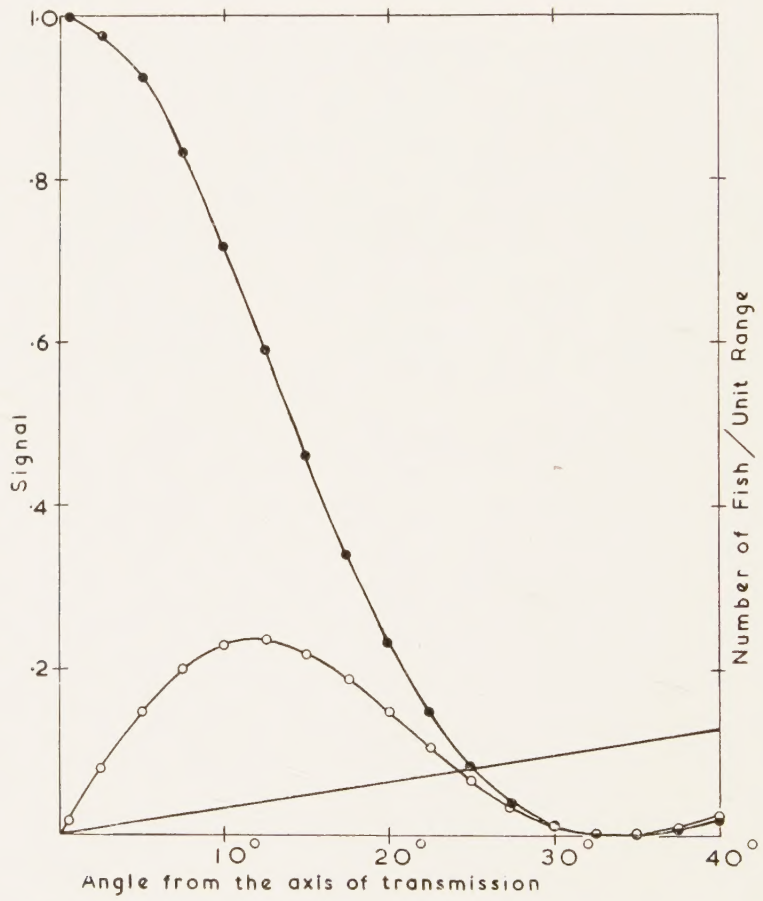


Fig. 13. *The distribution of received intensity of signal from a horizontal plate of fish in deep water.*

KEY ——— Number of fish.
●———● Transmitted signal in arbitrary units.
○———○ Received signal in arbitrary units.

improbable (with a machine less powerful than some present ones), the depth of the layer is somewhat over-estimated.

Three other uniform layers will be considered, a bottom 'scattering layer', which perhaps consisted of portunid crabs, that extended from Start Point to St. Catherine's, (Fig. 12(d)); the deep scattering layer, formed in all the deep oceans, (Fig. 12(f)) and the 'veil' trace of herring found deep in the Norwegian Sea in summertime, (Fig. 12(b)), at about 280 m. There are differences between the traces, e.g. the bottom layer has a spotty edge, the deep scattering layer shows some signs of patchiness (which may well indicate fish) and the 'veil' trace has a sharp upper edge; more striking, however, is the common characteristic of a uniform layer. Another common characteristic is the great horizontal extent of the layers.

There are thus three types of layer, the complex fish layer, the uniform fish layer and the uniform layer due to organisms other than fish. The patchy character of the first distinguishes it as fish, but there are no means of distinguishing the two forms of uniform layer. At a considerable depth, depth is probably a little over-estimated, but more important for characterizing layer traces are the depth range of its variations and their horizontal extent.

V. DISCUSSION

The chief result of the analysis of different forms of trace is that although much biological information is obtainable from echo traces (much more than has been exploited) a great proportion of the variations in shape and apparent size are effects of the directionality pattern of the oscillators. In a rough sort of way this has been obvious for a long time, but it has been less obvious that the depth of a fish trace is so rarely estimated accurately by the echo sounder. The depth errors of 'comets' could be large, those of a layer may be appreciable and even the depths of 'plumes' may be recorded wrongly.

Some of the information that the echo sounder yields has been ignored. Small 'comets' or sporadic CRT signals have often been described as single fish, but the only certain record of a single fish is the 'fingernail' trace. Again the vertical extent of a 'comet' at minimum range (excepting the horizontal plate) and the vertical extent of a 'plume' in its initial recording will give rough and usable estimates of the vertical extent of the shoal; it is not the full thickness of the shoal that is necessarily being measured, but it will be a minimum estimate of the thickness. Lastly there are possibilities of the categorization of complex shoals as being packed tightly or loosely with small shoals.

The simplest biological information provided by the echo sounder is on the size of shoals. There are subtleties of the packing of small shoals in large ones and the nature of the upper edge of a large shoal, but in the main the differences between the four types, and the differences between subtypes, are differences in shoal size. We find that 'comets' are caused by a wide range of fish species, as are 'plumes' and 'layers'.

Thus identification by the appearance of the trace depends primarily on variations in shoal size. This sometimes gives practicable identification, e.g. sprat shoals are smaller than herring shoals and so Richardson (1951) was able successfully to survey sprat concentrations in the southern North Sea. Identification by present methods (trawls and ring net gears, explosives, rippers, cameras and tangles) means that only large traces can be identified adequately. For example, for herring at Sandettié in December and pilchards in Mount's Bay in October, estimates of shoal size are usually superfluous. Identification is most needed on traces like those in Fig. 6(b) and Fig. 11(a) where there are two or three types of fish shoal and one wants to know which to catch.

An undercurrent in this paper concerns the nature of the signal returned from fish. It is between one tenth and one hundredth of the signal returned from the bottom; fish shoals can cast a shadow on the bottom and there is more than a hint of multiple reverberation. Common to these three facts is the idea of estimating the intensity of signal from a fish shoal. This has not been considered so far because of the difficulties of measurement.

Hodgson observed differences in pilchard, herring and mackerel, that are virtually differences in intensity. Some of these identifications do not always work, particularly in the Straits of Dover during the winter herring fishery, where many traces of different character

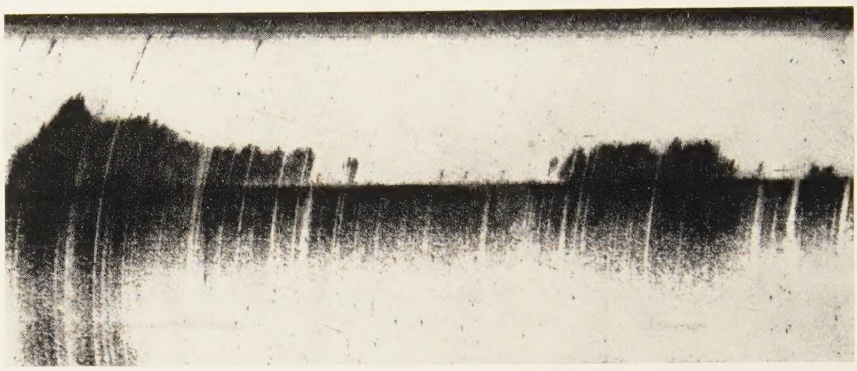


Fig. 14. *'Mountain' traces of horse mackerel off the Eddystone in January*, 1953.
(KH MS 26b)

may be found, any of which may be herring, pilchards or horse mackerel (Fig. 14 shows a trace of horse mackerel). However, Hodgson's original observation remains and needs confirmation with echo sounders which can measure the intensity of the signal returned from fish. Further progress on identification requires calibrated and measuring echo sounders.

VI. SUMMARY

The form of fish traces can give some information on the size and formation of fish shoals.

BIBLIOGRAPHY

Burd, A.C. and Lee, A.J. (1951). The sonic scattering layer in the sea. *Nature*, **167,** p. 624.

Cushing, D.H., Devold, F., Marr, J.C. and Kristjonsson, H. (1952). Some modern methods of fish detection. *F.A.O. Fish Bull.*, **5,** 3/4, p. 95.

Cushing, D.H., Lee, A.J. and Richardson, I.D. (in press). Echo traces of the thermocline.

Cushing, D.H. and Richardson, I.D. (1955). Echo-sounding experiments on fish. *Fish. Invest.*, Ser. II, XVIII, **4.**

Cushing, D.H. and Richardson, I.D. (1956). A record of plankton on the echo-sounder. *Journ. Mar. Biol. Ass. U.K.*, **35,** p. 231.

Furnestin, J. (1953). Ultra-sons et pêche à la sardine au Maroc. Les essais du bateau-de-pilote-pêche 'Jean François'. *Inst. Pêches Marit. du Maroc Bull.* No. 1.

Hodgson, W.C. (1950). Echo-sounding and the pelagic fisheries. *Fish. Invest.*, Ser. II, XVII, **4.**

Richardson, I.D. (1951). Echo-sounder surveys for sprats in 1950-51 season. *Ann. Biol. Cons. Internat. Expl. Mer*, VII, p. 97.

Schärfe, J. (1952). Fischlotungen auf Binnengewässern. *Der Fischwirt*, **3,** p. 1.

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By F. Mildner & Sons, London
(38435) Wt.2878 K.6 5/57 Gp. 1264